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Dynamic governance of the first wave of Covid-19 in Tunisia: An interoperability analysis

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Abstract

This study proposes an interoperability index of the measures taken by the Tunisian government during the first wave of the coronavirus disease 2019 (COVID-19) pandemic. In the first part, we present the process of decision making as a revised and adjusted process in continuous upgrading, based on the dynamic governance process in times of crisis. In the second part, we estimate an index that records the strictness of government policies in each subperiod and the degree of interoperability between the Tunisian pandemic responses against COVID-19 using subperiod instantiations. Our empirical findings show that the pandemic management strategy in Tunisia during the first wave was adjusted by incorporating new pandemic policies and changing the stringency levels over time. After estimating the interoperability index, we found that the measures taken early in a subperiod interact directly with the next successive subperiod in the decision process, but they interact indirectly with other successive subperiods.

KEYWORDS

coronavirus COVID-19, interoperability index, pandemic policies, Tunisia

Highlights

- The pandemic management strategy in Tunisia during the first wave has been adjusted by incorporating new pandemic policies and changing the stringency levels over time.
- Tunisia has reached the highest level of the strictness of government policies, after 18 days of initial responses taken during the first wave in a stepwise manner.

- The measures taken early in a subperiod interact directly with the next successive subperiod in the decision-making process, but they interact indirectly with other successive subperiods.
- Pandemic crisis cannot be managed or defeated with a single measure or policy, even at the highest stringency level. Instead, it is managed with several policy responses that interreact together over time.
- The establishment of a dynamic and flexible decision-making process can be useful in managing a future health crisis in countries whose public health systems suffer from several shortcomings.

INTRODUCTION

Since 2019, the world has been gripped by a new severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which was later named coronavirus disease 2019 (COVID-19) (Qiu et al., 2020). After being detected in the city of Wuhan in the Hubei province of China, COVID-19 spread rapidly, resulting in global human tragedy and tremendous economic damage (see, e.g., Baldwin & Weder di Mauro, 2020; Capano et al., 2020; Elgin et al., 2020; Krafft et al., 2021).

After recoding 120,000 cases and more than 4000 deaths worldwide, the World Health Organization (WHO) officially declared a global pandemic on March 11, 2020, recommending a range of measures and policies to manage this crisis. However, the political responses of governments cannot be uniform and they are influenced by the economic, social, health, political, and cultural factors of each country and each region. In this regard, Greer et al. (2020) argue that there is no way to understand the different responses to COVID-19 and their effects without understanding the social policies that assist in crisis management and state capacity (control over health-care systems and public administration). Therefore, understanding how countries were able to manage the first wave of this pandemic in an uncertain and dynamic environment can provide policymakers with arguments for their decisions with which to manage the waves that follow.

In the European Union (EU), for instance, the crisis reaction modes evolved in a multilevel governance system in which political arenas are interconnected. In this regard, Schomaker et al. (2021) argued that the EU's reaction in the first wave of the COVID-19 pandemic was based on centralized and decentralized decisions, and it was characterized by formal initiatives and informal actions given the EU has not developed a transboundary crisis management capacity, so far (Townend et al., 2020). On the other hand, the spread of COVID-19 has not spared the countries of the Middle East and North Africa (MENA), all of which are, to varying degrees and according to their means, engaged in the fight against the new, common enemy (Talbot, 2020). The Gulf countries, according to a March 2020 WHO preparedness assessment, have a sustainable capacity to respond to the coronavirus crisis due to the substantial investments in infrastructure and personnel that they have undertaken over the past 25 years (OCDE, 2020).

Some other countries in the MENA region have reacted to reduce the burden on the health system and have adopted rapid, decisive, and/or innovative measures to contain the virus, such as the smooth crisis management developed by Jordan, ramping up domestic masks and test production in Morocco, or using lessons learned from the past experiences in the fight against viruses in Egypt, which previously had eliminated the C virus, a liver disease caused by the hepatitis C virus (El Akkawi, 2020).

In Tunisia, the public health system is grappling with several issues such as gravely inadequate capacity, crumbling infrastructure, and regular shortages of medications, a situation that has been further worsened by the rising outflow of trained doctors and medical staff over the last few years. At the start of the pandemic, Tunisia only had an estimated 700 beds in intensive care units (public and private institutions combined) for about 12 million inhabitants. Moreover, not all of these beds were functional and only a few beds could be allocated exclusively for COVID-19 treatment. Furthermore, all Tunisians do not have the same level of access to these facilities. The crisis has indeed highlighted the regional disparities in access to health care, with most medical services, and particularly intensive care units, concentrated in the capital and coastal regions, and 13 out of 24 governorates having no reanimation beds, which are considered essential for COVID-19 patients. Furthermore, laboratories authorized to conduct COVID-19 testing are concentrated in the capital and in the coastal regions.

For the above-mentioned reasons, Tunisia has employed various measures to prevent the entry of the virus into the country. Once the virus circulates in the country, authorities are forced to adjust their strategy by adding new measures or by making the application of more stringent measures to decrease the rate of transmission of COVID-19 and to reduce the burden on the health system.

Pandemics often occur in waves. Thus, the measures taken can significantly reduce infection rates. However, they are costly and tiring, and therefore, typically cannot be sustained over a sufficiently long period. If fewer and fewer people follow pandemic policies, the virus returns and a second wave will start (Plümper & Neumayer, 2020). Moreover, pandemics and crises cannot be managed or defeated with a single measure or policy, even at the highest stringency level. They are managed by several policy responses that operate together over time to achieve a fixed objective. Based on the concept of dynamic governance developed by Neo and Chen (2007) and interpreting as the government's ability to continuously adjust the process in the formulation and implementation of public policies and programs that have interests to be achieved, this study focuses on quantifying the interoperability of the measures taken by the Tunisian government to manage the health crisis of COVID-19.

The decision-making process is described as a revised and adjusted process in continuous upgrading and can be summarized into *three major types*. First, thinking ahead is the capability to understand and formulate a strategy. Second, it creates feedback between the initial situation of the process and the new observations that allow for strategy revision and adjustment. Third, thinking across the process is continuous learning where the previous experience helps the current system evolve by incorporating new ideas or concepts. The process of thinking again has proven effective in several countries such as South Korea in MERS treatment, adopted in the policy formulation process in handling COVID-19, where they were able to reduce disease spread and deaths by looking at the health protocol owned, accompanied by observation and analysis of the ownership of the latest data (Kim, 2020).

The remainder of this paper proceeds as follows: “Background information” provides an overview of the COVID-19 epidemiological situation during the first wave in Tunisia and reviews the pandemic policies taken over time; “Data and methodology” presents our data sources and provides a detailed description of our empirical strategy; ”Empirical results and discussion” discusses the main results; and “Conclusion and policy implication” concludes the paper.

BACKGROUND INFORMATION

The first wave of the COVID-19 outbreak in Tunisia lasted for almost three and a half months. It began with the discovery of the first case on March 2, 2020, and it extended until June 13, 2020, the date of total control of the health situation, where zero new confirmed cases were recorded during several successive days.

As shown in Figure 1, the cumulative number of confirmed cases has increased over time, reaching 1087 cases by June 5, 2020. Given the weak capacity of the public health system in Tunisia, the major concern of the authorities was to prevent an exponential increase in COVID-19 cases during this period. In this regard, Figure 1 shows a linear trend increase in the cumulative case curve over short periods. From June 6, the curve became constant as the number of new cases reduced to zero for several successive days. To achieve these objectives, several measures and policies have been adopted and applied dynamically. To prevent the entry of the virus into Tunisian territory, since January 22, 2020, the government implemented early preventive measures, including screening at the point of entry and systematic 14-day isolation of travelers returning from high-risk areas (Talmoudi et al., 2020).

Following the report of the first confirmed case, an international traveler from Italy on March 2, 2020, additional measures were announced, and other decisions were taken to control the circulation of the virus in the country. On March 22, a national lockdown was imposed on the whole country for 2 weeks, which was extended twice before the return to the targeted lockdown and a total deconfinement on June 7, 2020.

As presented in Table 1, the decisions changed with the evolution of the epidemiological situation in the country. Before the imposition of the total lockdown, which was conducted between March 4 and March 20, 2020, the measures concerned the cancellation of public events, restrictions on international travel, public information campaigns, testing policy contact tracing, as well as the shutdown of workplaces and schools. All these measures were implemented with different degrees of stringency or were targeted to a specific category of individuals. On March 13, 2020, Tunisia officially entered epidemiological phase 3. To manage the consequences of the pandemic in the best possible conditions and mitigate its effects, some measures have become mandatory. Additionally, other measures that were nonexistent before March 13 have been implemented.

On March 20, a lockdown was imposed in Tunisia. Other than the measures taken previously, new measures were added, such as restriction on gatherings, closure of public transport, stay-at-home obligations, restriction of internal movement, income support, and debt relief/contracts for households.

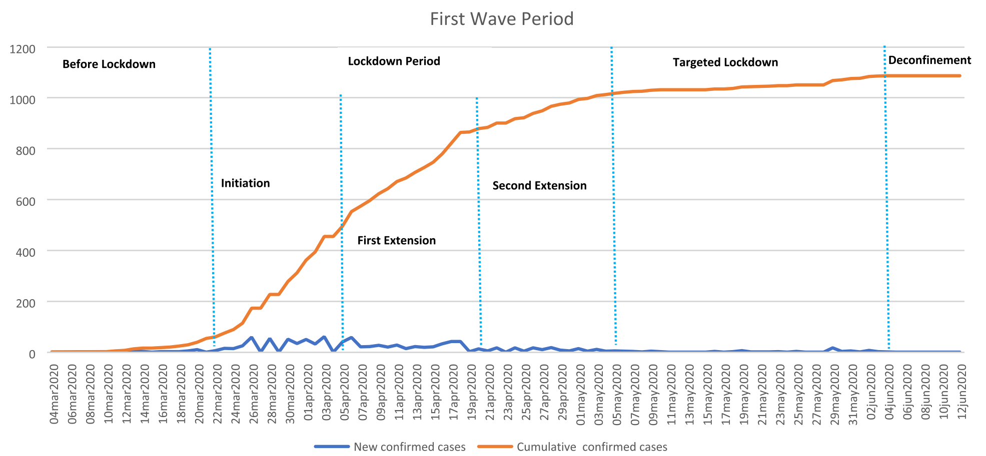

FIGURE 1 Evolution of cumulative confirmed COVID-19 cases and daily new confirmed cases during the first wave in Tunisia

TABLE 1 Policy responses during the first wave of the SARS-CoV-2 pandemic in Tunisia

Subperiods	Description	New policies and measures
P_1: [March 4, March 12]	Before lockdown	– Cancellation of public events – Restriction on international travel – Public information campaign – Testing policy – Contact tracing
P_2 [March 13, March 21]		– Workplace closing – School closing ⟹Change of stringency degree of P_1 measures
P_3 [March 22, April 4]	Lockdown	– Restriction on gatherings – Close public transport – Stay at home requirement – Restriction on internal movement – Income support – Debt contract ⟹Change of stringency degree of P_2 policies and measures
P_4 [April 5, April 19]	First extension lockdown	– No measures added – Nothing changed
P_5 [April 20, May 04]	Second extension lockdown	
P_6 [May 5, June 05]	Targeted lockdown	– No measures added ⟹Relaxing the stringency degree of P_3 policies and measures
P_7 [June 6, June 12]	Deconfinement	– No measures added ⟹Relaxing the stringency degree of P_6 policies and measures

Abbreviation: SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

After the registration of 61 new COVID-19 cases on April 4, Tunisia extended the COVID-19 lockdown twice, the first lasting until April 19, and the second lasting for 2 weeks until May 4. Thereafter, the situation became more stable, and a targeted lockdown was announced from May 5 until June 6. This period was characterized by a change in the degree of stringency and the partial removal of certain measures. The deconfinement period in this study officially corresponds to the third phase of the targeted lockdown in Tunisia. This period is characterized by a zero number of new cases for several successive days and the end of most political measures taken in previous periods against the spread of the coronavirus.

DATA AND METHODOLOGY

Data

To construct a database of the policy measures taken by Tunisia in response to the COVID-19 pandemic during the first wave, we used information provided by the Oxford COVID-19 Government Response Tracker (OxCGRT) (Hale et al., 2020a, 2020b). The OxCGRT database systematically collects publicly available information on several common policies taken in response to the pandemic. The different policy responses are tracked since January 1, 2020, cover more than 180 countries and are coded into 23 indicators. This tool provides data and produced five indices that aggregate the data into a single number

(Overall government response index, Containment and health index, Stringency index, Economic support index, and Risk of openness index).

Policy responses are classified into three categories in the OxCGRT. The first category includes containment and closure policies, such as the shutdown of schools and workplaces, cancellation of public events, restrictions on gatherings, stay-at-home requirements, restrictions on internal movement, and international travel controls. The second category concerns economic policies such as income support for households, debt/contract relief for households, fiscal measures, and international support. However, health system policies are grouped into the third category, which provides information on public information campaigns, testing policies, contact tracing, emergency investment in health care, and investment in vaccines (Hale et al., 2020a, 2020b).

To improve the validity and timeline of this information, we cross-checked this information using the CoronaNet data set based on the daily bulletins of the National Observatory of New and Emerging Diseases (ONMNE) in Tunisia. The CoronaNet Research Project compiled a database of government responses to the coronavirus. The main focus of this project was to collect information about the various fine-grained actions that governments are taking to address the effects of the COVID-19 pandemic (Cheng et al., 2020).

The ONMNE is a public administrative establishment run by the Ministry of Health and it was established in 2005 to meet the need to strengthen the capacity of the national health monitoring apparatus with respect to early detection and early warning against new and emerging diseases and potentially endemic indigenous diseases. ONMNE collects data on new and emerging diseases to improve the decision-making process and monitors the international epidemiological situation concerning rapidly spreading diseases to avoid or limit the risk of their cross-border introduction.

Based on CoronaNet data, we were able to identify the most important dates of the epidemiological situation in the country through the types of policies implemented on these dates. These policies provide indications of the evolution of the decision-maker's reaction politics during the first wave of COVID-19 in Tunisia.

Methodology

This paper proposes an interoperability index of the measures taken and adjusted by the Tunisian government during the first wave of COVID-19. The concept of interoperability is defined in this study as the ability of measures, public policies, or programs that have interests or objectives to be achieved, to operate together (see, e.g., Ford, 2008; Ford et al., 2007; Novakouski & Lewis, 2012; Rezaei et al., 2014). The period between March 4, 2020 and June 13, 2020 (hereafter denoted by S) corresponds to the entire first wave of the COVID-19 pandemic in Tunisia.

To identify the first wave of the COVID-19 pandemic in Tunisia, we denote this period as $S = [P_1, P_2, ...P_T]$, where P_i, $i = 1, ..., T$ are the subperiods that measure pandemic policies that are implemented, added, or modified. Once the set of subperiods has been identified, those subperiods are modeled using a set $X = \{M_1, M_2, M_3, ...M_n\}$, which represents the measures or decisions describing each subperiod.

These subperiod measures are represented by a set of states denoted by $C = \{c_1, c_2, ...c_n\}$, $c_i = [0, c_{max}]$. If M_i was not taken during the subperiod P_i, then its state c_i is equal to 0; otherwise, it can assume the value 1 if it was recommended or 2 when the application of this measure was mandatory. According to the dynamic governance (discussed above), the improvement of the decision-making process implies that if a measure is absent in P_i, it does not necessarily need to be absent in P_{i+1}. Similarly, when the government realizes the nonusefulness of a measure, it can relax it. Hence, the state assigned to a measure may change over time. Indeed, implementing and announcing measures and policies is not enough to manage the pandemic situation and its consequences, strictness in their application is needed as well. At this level, we calculate an index that records the strictness of government policies in each subperiod. This index is a simple average of the individual component indicators (measures), and is described as follows:

$$I_{\text{Stringency}}\,(P_i) = \frac{1}{k}\sum_{j=1}^{k} 100 \times \frac{V_j}{N_j},$$

where k is the number of component indicators, N_j is the maximum state value of the measure (indicator), and V_j is the recorded policy value on the ordinal scale in subperiod P_i.

Meanwhile, for each subperiod $P_i \in S$ characterized by a set of measures $m \subseteq X$, we denote $\sigma_i = m(P_i) = \{M_1(P_i);\ M_2(P_i);\ M_3(P_i), \ldots M_n(P_i)\}$, called the instantiation of P_i, which models P_i by the states of the measures in m.

Once all P_i have been instantiated, the subperiod instantiations must be aligned with each other to support meaningful subperiod comparisons and to indicate how the measures taken/added or modified during a subperiod P_i operated with those taken, modified, or added during the subperiod that follows. The alignment of the instantiation of the entire period S is given by the matrix $\sum = M(S) = \{\sigma_1; \sigma_2; \sigma_3; \sigma_4, \ldots \sigma_T\}$.

Based on the matrix $\sum$, we build a matrix of interoperability measurements for all subperiod pairs in S, using an interoperability function (Interop), for measuring the similarity of subperiods instantiations.

The choice of the interoperability function depends on the measure states with which the subperiods are modeled. Two types of functions are present in the literature: The first type concerns modeling with binary-valued measures states (0 if the measure is absent and 1 if the measure is taken during the concerned subperiod). In this case, the appropriate interoperability function is given by:

$$\text{Interop}_{\text{Bin}} = \frac{1}{n}\sum_{i=1}^{n} (\sigma'_{(i)} \wedge \sigma''_{(i)}),$$

where $\sigma', \sigma'' \in \{0, 1\}^n$ and $\wedge$ is the Boolean AND operator.

The second type concerns the modeling of subperiods with real-valued measure states $C = [0, c_{\max}]$. In this case, the following function is recommended:

$$\text{Interop}_{\text{Real}} = w.\ \text{MMS} = \left[\frac{\sum_{i=1}^{n}\sigma'_{(i)} + \sum_{i=1}^{n}\sigma''_{(i)}}{2n.\ c_{\max}}\right]\left[1 - \left(\frac{1}{\sqrt[r]{n}}\right)\left(\sum_{i=1}^{n} b_{i\left(\frac{\sigma'_{(i)}-\sigma''_{(i)}}{c_{\max}}\right)^{r}}\right)^{1/r}\right],$$

$$b_i = \begin{cases} 0 & \text{if} \quad \sigma'_{(i)} = 0 \quad \text{or} \quad \sigma''_{(i)} = 0, \\ 1 & \text{else}, \end{cases}$$

where w is the mean value of the states characterizing two modeled subperiods, and MMS is the modified Minkowski similarity function. n is the number of measures used to model two subperiods, $c_{\max}$ is the maximum value of the measured states, and r is the Minkowski parameter (usually set to $r = 2$). $\text{Interop}_{\text{Real}}$ has the capability of yielding very precise similarity measures of subperiod instantiations limited only by the number of measures and the precision of the states of these measures.

Given two subperiods, P_i and $P_j \in S$ instantiated with σ_i, σ_j and an interoperability function (Interop), then, $m_{ij} = \text{Interop}(\sigma_i, \sigma_j)$ is the interoperability measurement of P_i and P_j. The interoperability matrix is given by $M = [m_{ij}]; i, j \leq |S|$ for all pairs of subperiods (P_i, P_j) as

$$M = \begin{matrix} & \begin{matrix} P_1 & \dots & P_T \end{matrix} \\ \begin{matrix} P_1 \\ \vdots \\ P_T \end{matrix} & \begin{bmatrix} 0 & \dots & m_{1T} \\ m_{ij} & 0 & \vdots \\ m_{ij} & \dots & 0 \end{bmatrix} \end{matrix}.$$

In this study, we assume that measures taken early in a subperiod interact directly with the next successive subperiod in the decision process, but they interact indirectly with every successive subperiod in the process because the information they create or transform is eventually passed to successive sub-periods. No self-interoperability is assumed, so the diagonal of the interoperability matrix M will take a value of 0.

EMPIRICAL RESULTS AND DISCUSSION

Responses stringency, duration, and change during the first wave of COVID-19

Tunisia like several countries around the globe initiated the first responses against COVID-19 after the organization of the research and innovation forum on COVID-19 by the WHO on February 11 and 12, 2020. These measures have been adjusted over time according to the evolution of the epidemiological situation in the country.

Table 2 shows that the policy responses against COVID-19 during the first wave in Tunisia changed from one subperiod to another. These changes are observed in the new policy measures taken during each subperiod and in the adopted stringency level.

During the first subperiod P_1, the Tunisian authorities chose to recommend the cancelation of public events and imposed restrictions on international movement only in certain countries such as Italy, France, and Egypt. At the same time, public officials began to urge caution against the new virus. In terms of health, the Tunisian strategy is based on testing all those carrying the symptoms of the virus, meeting specific criteria, and tracing the contacts of certain positive cases.

The testing policy did not change during the whole period of the first wave of the virus and included the second subperiod P_2, which kept the same measurements taken in P_1 but with different degrees of rigidity.

We note that the cancelation of public events has become mandatory after being recommended in P_1. In addition, restrictions on international travel were imposed in all countries, and information campaigns became more intensive with coordination between traditional and social media.

Meanwhile, new measures and policies were implemented during the second subperiod, P_2. For example, the closure of schools and universities was imposed on all levels and categories. In addition, the closure of some workplaces was recommended or worked for a few hours, in groups, or with reduced capacity. Additionally, people were urged to avoid large gatherings. Enforcement of this latest ruling became mandatory during the P_3, P_4, and P_5 subperiods. During these subperiods (P_3, P_4, and P_5), the closure of workplaces was required for all activities except essentials. However, all other measurements taken in P_1 and P_2 were maintained at the same levels of rigidity and inclusiveness as P_2.

The new measures that came into effect during the P_3 subperiod were recommendations to reduce the volumes, routes of the main means of transport, the requirement not to leave the home except for necessities, curfews, imposition of restrictions on internal movement and support workers in the informal sector, the poor, and workers in the private sector who lost their wages and reduced debts and contracts for households.

TABLE 2 Policy responses, coding, and change during the first wave of COVID-19

Policy responses	Coding/states	Subperiods						
		P_1	P_2	P_3	P_4	P_5	P_6	P_7
M_1: Cancel public events	**1-** No measures							√
	2- Recommend canceling	√						
	3- Require canceling		√	√	√	√	√	
M_2: Restriction on international travel	**1-** No restrictions							
	2- Restrictions on one or more countries, but not all countries.	√						
	3- Restrictions on all countries		√	√	√	√	√	√
M_3: Public information campaign	**1-** No COVID-19 public information campaign							
	2- Public officials urging caution about COVID-19	√						
	3- Coordinated public information campaigns across traditional and social media and intensification.		√	√	√	√	√	√
M_4: Testing policy	**1-** No testing policy							
	2- Testing those who have symptoms or meet specific criteria	√	√	√	√	√	√	√
	3- Open public testing							
M_5: Contact tracing	**1-** No contact tracing							
	2- Contact tracing not done for all cases	√	√	√	√	√		
	3- Contact tracing done for all identified cases						√	√
M_6: School closing	**1-** No measures	√						
	2- Recommend closing schools for some levels							√
	3- Require closing schools for all levels and categories		√	√	√	√	√	
M_7: Workplace closing	**1-** No measures	√						√
	2- Recommend closing or work from home or restricted opening hours/groups or not all capacity for some businesses and government activities		√				√	
	3- Require closing all but keep essential workplaces (grocery stores, doctors, etc.)			√	√	√		
M_8: Restrictions on gatherings	**1-** No measures	√						√
	2- Recommend avoiding large gatherings		√					
	3- Require restrictions on gatherings			√	√	√	√	
M_9: Public transport closing	**1-** No measures	√	√					√
	2- Recommend significantly reducing volume/route/means of transport available			√	√	√	√	
	3- Require closing public transport							

TABLE 2 (Continued)

Policy responses	Coding/states	Subperiods P_1	P_2	P_3	P_4	P_5	P_6	P_7
M_{10}: Stay at home requirements	**1-** No measures	√	√					√
	2- Recommend not leaving the house						√	
	3- Require not leaving the house except for daily exercise, grocery shopping, and essential trips			√	√	√		
M_{11}: Restriction on internal movement	**1-** No measures	√	√					√
	2- Recommend no traveling between region cites							
	3- Internal movement restrictions in place and curfew applied			√	√	√	√	
M_{12}: Income support	**1-** No measures	√	√					
	2- Government transfers support to informal workers, poor and private formal workers who lost salary			√	√	√	√	√
	3- Government transfers support to informal workers, poor and public and private formal workers who lost salary							
M13: Debt/contract relief	**1-** No debt/contract relief	√	√					
	2- Narrow relief, specific to one kind of contract							
	3- Broad debt/contract relief			√	√	√	√	√

Note: √ indicates the measure (policy) states during each subperiod.

All these measures were applied during the three subperiods P_3, P_4, and P_5 with the same level of rigidity and inclusiveness. However, we observed some changes during the P_6 subperiod. First, the contact tracing strategy became more inclusive by tracking all identified cases of the virus. In addition, we noticed the resumption of activities in groups or with reduced capacities with the opening of workplaces for a few hours. As a result, the request to stay at home was recommended and not required, as it was previously.

This gradual removal of restrictions occurred during subperiod P_7. As shown in the last column of Table 2, the total removal of restrictions concerns internal movements, mass gatherings, events, and public transport. In addition, workplaces, schools for certain levels, and universities were opened with the application of health protocols appropriate to each sector. We noted that aid transfer and debt relief were also present during P_7.

Subperiods instantiations and stringency index

The degree of interoperability between the Tunisian pandemic responses against COVID-19 during the first wave is estimated using subperiod instantiations, in which each subperiod is modeled by three coded states reflecting the dynamics of measures stringency and inclusiveness. The subperiod instantiations are as follows:

$$\sigma_1 = m(P_1) = \{1;1;1;1;1;0;0;0;0;0;0;0;0\} \implies I_{\text{Stringency}}(P_1) = 12.50\%,$$

$$\sigma_2 = m(P_2) = \{2;2;2;1;1;2;1;1;0;0;0;0;0\} \implies I_{\text{Stringency}}(P_2) = 50.00\%,$$

$$\sigma_3 = m(P_3) = \{2;2;2;1;1;2;2;2;1;2;2;1;2\} \implies I_{\text{Stringency}}(P_3) = 93.75\%,$$

$$\sigma_4 = m(P_4) = \{2;2;2;1;1;2;2;2;1;2;2;1;2\} \implies I_{\text{Stringency}}(P_4) = 93.75\%,$$

$$\sigma_5 = m(P_5) = \{2;2;2;1;1;2;2;2;1;2;2;1;2\} \implies I_{\text{Stringency}}(P_5) = 93.75\%,$$

$$\sigma_6 = m(P_6) = \{2;2;2;1;2;2;1;2;1;1;2;1;2\} \implies I_{\text{Stringency}}(P_6) = 81.25\%,$$

$$\sigma_7 = m(P_7) = \{0;2;2;1;2;1;0;0;0;0;0;1;2\} \implies I_{\text{Stringency}}(P_7) = 18.75\%.$$

These instantiations of the subperiods were done using 13 main measures and policies implemented by Tunisia to manage the first wave of the pandemic. The government policy stringency index is estimated directly from subperiod instantiations using the measures M_1, M_2, M_6, M_7, M_8, M_9, M_{10}, and M_{11} (Table 2).

Between March 4 and March 12, only five measures were implemented to control the circulation of the virus in Tunisian territory, representing 38% of all political responses taken during the first wave of COVID-19 in Tunisia. The degree of rigor of these measures is low, and it is estimated to be 12.50% during the P_1 subperiod.

On March 13, 2020, Tunisia officially entered epidemiological phase 3. This development forced the Tunisian authorities to add three new measures and increase the level of stringency of P_1 measures. We estimated the degree of rigor during P_2 by 50%. However, this change did not last long (1 week), after which Tunisia entered full containment, and five additional measures were added from March 22. During the P_3 subperiod, the level of stringency of government pandemic responses reached an estimated maximum of 93.75%. With this maximum level, Tunisia managed the two subperiods P_4 and P_5.

Unlike Egypt and Ethiopia that initiated their responses late and upgraded to a high response level in a very short time, Tunisia reached the highest level of the strictness of government policies, after 18 days of initial responses taken during the first wave in a stepwise manner (Ma et al., 2021). Additionally, Tunisia adjusted their response stringency to a high level only after WHO declared COVID-19 as a pandemic. This indicates that the announcement of COVID-19 pandemic triggered Tunisia to act more aggressively against COVID-19.

With such a maximum level of rigor, Tunisia managed the two subperiods P_4 and P_5 as well. The presence of 13 measures applied with a maximum stringency level led to the remarkable stability of the epidemiological situation in the country. The number of new cases per day fell to 10 cases on average during P_5. after having been approximately an average of 30 cases in P_3 and P_4.

In this same vein, Tunisia like the Netherlands and Denmark took a shorter time to reach reduced peak daily case (32, 36, and 41 days, respectively). Compared to Japan and Singapore where the time to the reduced peak daily new case was long (96 and 115 days respectively), Tunisia had an early achieve a reduced peak of new cases (Ma et al., 2021).

This stability was translated by a reduction in the level of policy stringency, which decreased to 81.25% in P_6 and fell to 18.75% during the P_7 subperiod, keeping only 53.8% of measurements that were present during P_5 and P_6.

Interoperability analysis of pandemic policies

In this section, we first present the degrees of interoperability between the measures taken or adjusted during two successive subperiods and then present the interoperability matrix of all subperiod pairs. Given the variation in the pandemic response states between 0 and 2, our estimates are based on the modified Minkowski similarity function and are presented as follows:

$$m_{12} = \text{Interop}\ (\sigma_1; \sigma_2) = \frac{5+12}{2\times 13\times 2}\left[1 - \frac{1}{\sqrt[2]{13}}\left(\frac{1}{4}+\frac{1}{4}+\frac{1}{4}+1+\frac{1}{4}+\frac{1}{4}\right)^{\frac{1}{2}}\right],$$

$$m_{12} = \text{Interop}(\sigma_1; \sigma_2) = 0.327\times 0.583 = 0.190,$$

$$m_{23} = \text{Interop}\ (\sigma_2; \sigma_3) = 0.654\times 0.446 = 0.291,$$

$$m_{34} = \text{Interop}\ (\sigma_3; \sigma_4) = 0.846\times 1 = 0.846,$$

$$m_{45} = \text{Interop}\ (\sigma_4; \sigma_5) = 0.846\times 1 = 0.846,$$

$$m_{56} = \text{Interop}\ (\sigma_5; \sigma_6) = 0.827\times 0.76 = 0.628,$$

$$m_{67} = \text{Interop}\ (\sigma_6; \sigma_7) = 0.615\times 0.444 = 0.273.$$

The degree of interoperability between the measurements of P_1 and P_2 was estimated as $m_{12} = 0.190$. This low interrogability between the two subperiods P_1 and P_2, is mainly due to the number of measurements added in P_2 and also to the modification of the degree of rigidity of measures taken at P_1. In other words, this low degree of interoperability reflects the weak reaction of the average Tunisian public decision-maker to the evolution of the epidemiological situation. This reaction relatively improved in P_3 with the addition of new measures with a maximum level of stringency. Consequently, the degree of interoperability between P_2 and P_3, estimated by $m_{23} = 0.291$, also increased. Indeed, the number of measurements and their level of rigidity did not change during P_4 and P_5, which led to the estimation of the same degree of interoperability by $m_{34} = m_{45} = 0.846$ between P_3 and P_4, and between P_4 and P_5. This degree is the highest during the entire period and is explained by the prolongation of total confinement twice in P_4 and P_5. Furthermore, the ban of large gatherings measure was required during the subperiods P_3, P_4, and P_5, which targeted toward large gatherings of people and may thus prevent so-called "super-spreader events," which have been shown to account for a substantial fraction of the total number of infections (e.g., Adam et al., 2020; Lemieux et al., 2020; Wang et al., 2020).

By switching to targeted confinement, the rigidity of certain measurements was relaxed, and the degree of interoperability between P_5 and P_6 was estimated as $m_{56} = 0.628$. This decrease is mainly due to the modifications made to measure M_{10} represents the demand to stay at home, which became recommended after being required, and to measure M_7 with the partial opening of workplaces while reinforcing contact tracing.

The transition from the full to partial to no lockdown appears to be a more effective strategy of lifting the restrictions and can be explained by economic reasons. Demirgüç-Kunt et al. (2020) showed that countries that adopted a gradual, staged reopening experienced stronger economic recovery compared with the countries that rushed into lifting the restrictive measures before the pandemic was under control.

During the P_7 subperiod, the measures M_1, M_7, M_8, M_9, M_{10}, and M_{11} were removed and M_6 was relaxed. All these modifications in terms of management led us to estimate the interoperability index between P_7 and P_6, by $m_{67} = 0.273$. In contrast, the interoperability between the measures taken or modified over time during the first wave is estimated using the following interoperability matrix:

P_i	P_1	P_2	P_3	P_4	P_5	P_6	P_7
P_1	0.000	0.190	0.130	0.130	0.130	0.160	0.172
P_2	0.190	0.000	0.291	0.291	0.291	0.317	0.153
P_3	0.130	0.291	0.000	0.846	0.846	0.628	0.212
P_4	0.130	0.291	0.846	0.000	0.846	0.628	0.212
P_5	0.130	0.291	0.846	0.846	0.000	0.628	0.212
P_6	0.160	0.317	0.628	0.628	0.628	0.000	0.273
P_7	0.172	0.153	0.212	0.212	0.212	0.273	0.000

From this matrix, there is evidence that measures taken early in a subperiod interact directly with the next successive subperiod in the decision process, but they interact indirectly with every successive subperiod in the process because the information they create or transform is eventually passed to successive subperiods. This matrix could enhance understanding of the evolution of the managerial behavior of Tunisian public decision-makers over time by observing the measures taken at each subperiod and their stringency degrees.

Additionally, there is clear evidence that a pandemic crisis cannot be managed or defeated with a single measure or policy, even at the highest stringency level. Instead, it is managed with several policy responses that interreact together over time. In this regard, Banholzer et al. (2021), using a semi-mechanistic Bayesian hierarchical model, showed that the combination of some nonpharmaceutical interventions leads to a strong reduction in the number of new infections. Furthermore, Gurevich et al. (2021), using evo-epidemiological model, have shown that the timely application of nonpharmaceutical measures could significantly manage the COVID-19 crisis and may act to reduce virulence.

CONCLUSION AND POLICY IMPLICATION

In this study, we analyzed the interoperability of the measures taken by the Tunisian government to manage the first wave of the COVID-19 pandemic. The first wave of the COVID-19 pandemic in Tunisia lasted for almost three and a half months. It started after the discovery of the first case on March 2, 2020, and it extended until June 13, 2020, the date of total control of the health situation, where zero new confirmed cases were recorded during several successive days. The pandemic policies documented in this study are classified based on their implemented dates. This response classification allowed us to break down the first wave period into seven successive subperiods. Then, we modeled each subperiod using three coded states, which reflect the dynamics of measures in terms of their stringency and inclusiveness. The results obtained show that the process of making decisions during the first wave in Tunisia were revised and adjusted in continuous upgrading, in which policy responses were changed from one subperiod to another. This change is observed in the new policy measures implemented during each subperiod and in the adopted stringency level.

The establishment of a dynamic and flexible decision-making process can be useful in managing a future health crisis in countries whose public health systems suffer from several shortcomings.

By estimating the stringency index, we found that, as of March 23, the level of stringency of government responses to the pandemic reached an estimated maximum of 93.75%. With such a maximum level of rigor, Tunisia also managed the two subperiods where total containment was extended twice. Consequently, the presence of 13 measures applied with a maximum level of rigor led to the remarkable stability of the epidemiological situation in the country, with the number of new cases per day falling to 10 cases on average during the second extension of confinement after having been approximately an average of 30 cases at the start of the lockdown subperiod. This stability resulted in a reduction in the level of policy stringency, which decreased to 81.25% during the targeted containment and fell to 18.75% during the total deconfinement subperiod characterized by the end of several previously implemented policies. The transition from full lockdown to partial or no lockout appears to be a more effective strategy to lift restrictions without worsening the health situation.

However, after estimating the interoperability index, we found that the measures taken early in a subperiod interact directly with the next successive subperiod in the decision-making process, but they interact indirectly with other successive subperiods. An important implication that arises from this study is that a pandemic crisis cannot be managed or defeated with a single measure or policy, even at the highest stringency level. Instead, it is managed with several policy responses that interreact together over time.

There are some limitations to this study. First, the methodology of interoperability requires the presence of a set of decisions that change over time and have the same objective to achieve. This is not well identified for the other waves in Tunisia. In addition, the decision-making time is not the same for all countries, which makes the comparison of crisis management modes between countries difficult.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

ETHICS STATEMENT

On behalf of my coauthors, I attest to the fact that all authors have read the manuscript and the validity and legitimacy of the data and its interpretation. We confirm that we have read and have abided by the statement of ethical standard for manuscripts submitted to *World Medical & Health Policy* (WMHP).

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